PCT/AU00/00099

09/890698

REC'D 14 MAR 2000

WIPO PCT

Patent Office
Canberra

I, KAY WARD, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PP 8655 for a patent by THE UNIVERSITY OF SYDNEY filed on 12 February 1999.

COMMONWEALTH OF AUSTRALIA
AUSTRALIA
PATENT OFFICE

WITNESS my hand this
Eighth day of March 2000

K Ward

KAY WARD
TEAM LEADER EXAMINATION
SUPPORT AND SALES

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN
COMPLIANCE WITH RULE 17.1(a) OR (b)

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant(s):

THE UNIVERSITY OF SYDNEY

Invention Title:

LASER ETCHING OF WAVEGUIDE STRUCTURES

The invention is described in the following statement:

LASER ETCHING OF WAVEGUIDE STRUCTURES

Field of the Invention

The present invention relates to the construction of waveguide devices and the processing of semi-conductor wafer structures and, in particular, discloses utilizing a laser system to locally process a wafer.

Background of the Invention

In the construction of optical waveguide devices, it is common for many significant problems to occur which may affect the operational characteristics of optical devices. For example, as illustrated in Fig. 1, optical devices are often constructed utilizing an adaption of semiconductor fabrication techniques and can commonly include a number of layers 2 constructed on a silicon substrate 1. As a result of differential thermal expansion coefficients of the materials 1, 2, various compressive stresses are induced during normal operating conditions. These stresses can have the effect of changing the operational characteristics of any device formed on substrate 1. In particular, the compressive stresses can often give rise to anisotropic birefringent properties in optical waveguides which can substantially effect their operation.

Interim solutions suggested have included techniques such as employing hybrid technologies where bulk polarizing elements are slotted into an optical chip and set to compensate for birefringence (Hida, Y., Inouse, Y., Hanawa, F., Fukumitsu, T., Enomoto, Y., Takato, N., Proceedings of European Conference on Optical Communications (ECOC'98), p321, Madrid Spain, 1998); or providing time consuming etching steps for etching strain relieving grooves on either side of a waveguide (Nadler, Ch., Lanker, M., Wildermuth, E., Hunziker, W., Melchior, H., Proceedings of European Conference on Optical Communications (ECOC'98), p367, Madrid Spain, 1998), or treatment via a UV laser to create damage at the substrate which leads to a compensating stresses (Albert, J.,

Bilodeau, F., Johnson, D.C., Hill, K.O., Mihailov, SJ., Strychman, D., OSA Proceedings of Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides; Applications and Fundamentals, Williamsburg, USA, 1997).

The utilization of UV laser treatment has significant problems in that the lasers are expensive, unreliable in a manufacturing environment. They require constant skilled maintenance and are difficult to provide environmental stability.

Hence, other forms of processing are generally needed.

Summary of the Invention

It is an object of the present invention to provide for a more effective form of treating of a waveguide substrate so as to improve the operational characteristics of any device formed on the waveguide.

In accordance with a first aspect of the present invention, there is provided a method of processing a waveguide device structure formed in a layer deposited on a substrate, the method comprising the step: (a) utilizing a laser device to provide predetermined localized heating of a top surface of the layer.

The laser can comprise a carbon dioxide laser source and the heating, in one embodiment, can include ablation of the top surface of the structure. The localized heating can be utilized to alter the birefringent properties of the structure such that the TM and TE birefringent modes are preferably substantially aligned by the heating.

The step (a) further can comprise masking the top surface with a thermally conductive material having an aperture defined therein through which the emmission from the laser passes.

In one embodiment, the waveguide device structure preferably can include a core structure and the localized heating occurs between the core structure and the top surface. Otherwise the localized heating can occur along

an elongated track parallel to and spaced apart from the core structure.

In one embodiment, the structure can comprise a sensor and localized heating causes the ablation of the top surface adjacent the core. In another embodiment there is provided a further step (b) of depositing further material layers on the top surface so as to form a semiconductor device.

In another embodiment the step (a) can be repeated along predetermined intervals of the waveguide device structure so as to form a grating structure.

The aforementioned aspect has a number of other uses. In particular, it can be used to provide for accelerated aging of components by means of CO_2 thermal heating. of optical devices such as UV processed gratings formed on a planar waveguide. The accelerated aging can provide for improved operational characteristics and can include precise localised aging of components. Further, the thermal annealing can be utilized to anneal out the UV processing of portions of a previously processed waveguide. This can be taken to the extent of almost totally annealing out the UV processing effect.

Further, the present invention is also directly applicable to fibre devices.

In accordance with a further aspect of the present invention, there is provided an apparatus when constructed in accordance with the method as set out above.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 illustrates the creation of a compressive stress in a wafer structure;

Fig. 2 illustrates schematically the operation of the method of the preferred embodiment;

Fig. 3 illustrates the ablation of a wafer

surface;

Fig. 4 illustrates the change and effective index in an experiment utilizing the preferred embodiment;

Fig. 5 illustrates a further change in the effective index of an experiment utilizing the preferred embodiment;

Fig. 6 illustrates the initial profile of a Mach-Zehnder (MZ) interferometer prior to application of preferred embodiment showing both the TM and TE modes;

Fig. 7 illustrates the spectral response for TE and TM modes of a MZ interferometer after application of the preferred embodiment for the device of Fig. 6;

Fig. 8 illustrates an alternative form of processing a wafer;

Fig. 9 illustrates the process of ablation around a core of a waveguide;

Fig. 10 illustrates the utilization of ablation in changing the device characteristics of a waveguide;

Fig. 11 illustrates the utilization of ablation in conjunction with deposition of further layers on a wafer; and

Fig. 12 illustrates the construction of a long period lossy grating.

Description of Preferred and Other Embodiments

In the preferred embodiment, an inexpensive and relatively compact CO_2 laser device is utilized to provide mid infrared laser processing of a waveguide structure so as to obtain both birefringence compensation and tuning of optical components. The processing set up is illustrated schematically in Fig. 2 wherein a waveguide 3 is subjected to ablation utilizing a CO_2 laser 5. An example of the ablation processing is illustrated in Fig. 3 wherein a waveguide 6 having a internal core 7 is processed so as to include ablation channels 8, 9. In a first example, the CO_2 laser was used to enhance the device characteristics of an asymmetric Mach-Zehdner (MZ) interferometer fabricated utilizing hollow-cathode PECVD techniques.

The mid-IR radiation was used to thermally relax stresses at the core and substrate as well as affect a change in the refractive index. At sufficiently high temperatures, the core and cladding waveguide glasses can be softened, melted and vaporised. These ablation processes themselves can be used to generate faster relaxation than would otherwise be possible as well as provide a source of polarisation dependent loss for energy stripping within waveguides for functions such as optical attenuators, and a means of etching generally for other more classical applications, including the laser etching of stress-relieving grooves. Most heating was found to occur through non-radiative transfer of absorbed light into vibrational modes of the silica molecule.

For given exposures utilized in experiments, the substrate temperature was thought to be approximately the same as that induced at the surface. The laser was operated initially with unfocussed 10W of CW power (~ 140W/cm^2). When the laser was later focused, temperatures readily exceed the melting point of silica were achieved resulting in laser vaporisation and etching (ablation).

Since the asymmetric MZ spectral response is characteristic of the interferometer established between the input and output couplers, birefringence compensation, as measured by matched TE and TM spectra (the TM identified to have a higher effective index by writing a weak Bragg grating in a straight waveguide manufactured on the same wafer), can be achieved between the two couplers. From an experimental point of view, if true birefringence reduction in this region is demonstrated, the change in TE and TM notch wavelength due to an increase in effective index must be such that they converge when processing the longer arm, and diverge when processing the shorter arm. The reverse is the case for a decrease in refractive index. Otherwise, spectral compensation of polarisation is possible within a MZ whilst actually worsening the intrinsic polarisation dispersion. When convergence is achieved, then the

feasibility of polarisation compensation can be established which is generally applicable to other optical components and straight waveguides as well as the asymmetric MZ device chosen here.

In the experiments to determine the parameters of operation, optical spectra were taken, of the MZ device using a broadband erbium-doped fibre amplifier (EDFA) and a spectrum analyser with a resolution of 0.05nm, limiting the birefringence splitting which can be measured to -1×10^{-5}.

In initial experiments, the longer arm of a MZ device (12µm SiO_2 cladding and buffer layers, 4x5µm GeO_2-doped core, $\Delta n - 0.01$) was processed for testing and confirmation of the concept. Measurements were taken at intervals after briefly halting the exposure at fixed times since the fibre coupling was increasingly affected by longer exposures. It was noted that both TE and TM shifted to longer wavelengths indicating an increase in refractive index. The TE effective index eventually increased more rapidly such that the splitting was reduced as shown in Fig. 4 which shows the change in wavelength splitting between TE and TM eigenstate with exposure to unfocussed light. Initially, however, as shown in Fig. 4, an increase in the splitting observed. We believe is related to an initial increase in compressive stress and subsequent compaction of the core glass. The magnitude of reduction is sufficient to allow compensation of birefringence in most planar silica-on-silicon devices where the splitting is much lower than the device chosen here. Further, this value is unsaturated.

In principle, this result might be achieved by placing the entire device in an oven although the accuracy and duration of the exposure make this a less attractive option.

The power density of the CO_2 laser was then increased to $-1.3 kW/cm^2$ by focussing to a 100µm spot size such that we exceed the threshold necessary for vaporisation for an exposure of less then 0.2s. Ablation

was confirmed under an optical microscope after gently cleaving through one damage region of the surface. By controlling the duration of the exposure it was possible to control the depth to which material is removed. The spectral responses when exposing the longer arm were found to shift to shorter wavelengths indicating a decrease in refractive index. However, the TM state was found to decrease more rapidly resulting in a large drop in the birefringence splitting. The decrease in refractive index and the localised ablation indicates that in this case dilation and stress compensation or relaxation at the core are the main factors responsible for the reduction in birefringence. Fibre coupling is significantly more stable (an important advantage for *in-situ* monitoring) and the process is clearly more efficient than thermal annealing of the material. This will affect the effective propagation constants for each polarisation state as well as introduce some polarisation dependent loss. The result is that this can be used to achieve balancing of the optical energy for each eigenstate and hence result in a matched and improved spectral response of the device. Fig. 5 shows the change in effective index as a function of shots fired in the same region and shows the convergence of birefringence when exposing the longer arm. It was noted that subsequent successive shots on the same region did not contribute any further. Indeed a small reversal was observed. Exposing the shorter arm showed spectral divergence, as expected if polarisation compensation has been achieved.

The spectral response for a second device utilized in experiments (essentially a polarisation splitter) prior to irradiation is shown in Fig. 6. The poor fringe contrast and the difference between TE and TM responses indicates that the input coupler is polarisation sensitive and that different amounts of light are split for each eigenstate. As a result, the intensity of light in each arm is not equal leading to poor fringe contrast upon recombination at the output coupler, particularly in this

case of the TE state. The polarisation sensitivity between couplers is very difficult to eliminate completely in silica-on-silicon systems where strain is not readily removed. Fig. 7 illustrates the end results on the device once the process of irradiation ablation was optimised. An improvement is fringe contrast to 20dB for both TE and TM states was achieved after five shots along the longer arm (power density -10kW/cm^2). The total increase in loss necessary to balance the polarisation states in this particular device was -wdB for TM and -1.2dB for TE.

A number of further modifications and applications of the aforementioned technique are possible. Firstly, the utilisation of the CO_2 laser can be refined as illustrated in Fig. 8 by utilizing a metal plate 20 containing a slot 21 with the metal plate acting as a heat sink so as to extract heat from the laser beam 22 outside specific locations. In this manner, more refined processing 23 of the waveguide can be achieved.

Secondly, the ablation of the waveguide can also be extended, as shown in Fig. 9, to the area surrounding the core 25. This can be utilized to effect the operation of the core and the overall device. For example, in Fig. 10, there is illustrated the utilization of ablation to form a refined surface 30 which can be utilized to provide for more accurate sensing by the core 31. Further, the ablation of the surface can be utilized in the construction of complex semi-conductor devices having predetermined operational characteristics. For example, in Fig. 11, there is illustrated the example of deposition of a subsequent layer 33 which can comprise zinc oxide (ZNO), $BiTO_3$ or the like so as to provide for a functional semiconductor device.

A further example refinement is illustrated in Fig. 12 where a series of ablations 40-42 are written at regular intervals along a core 43 so as to provide for a long period "loss" grating structure.

Other applications an include modification of

polarization controllers and attenuators etc.

The aforementioned laser process has a number of other uses. In particular, it can be used to provide for accelerated aging of components by means of CO_2 thermal heating. of optical devices such as UV processed gratings formed on a planar waveguide. The accelerated aging can provide for improved operational characteristics and can include precise localised aging of components. Further, the thermal annealing can be utilized to anneal out the UV processing of portions of a previously processed waveguide. This can be taken to the extent of almost totally annealing out the UV processing effect.

Further, the above processing steps are also directly applicable to fibre devices.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

We Claim:

1. A method of processing a waveguide device structure formed in a layer deposited on a substrate, the method comprising the step:

(a) utilizing a laser device to provide predetermined localized heating of a top surface of said layer.

2. A method as claimed in claim 1 wherein said laser comprises a carbon dioxide laser source.

3. A method as claimed in any previous claim wherein said heating includes ablation of the top surface of said structure.

4. A method as claimed in any previous claim wherein said localized heating is utilized to alter the birefringent properties of said structure.

5. A method as claimed in claim 4 wherein the TM and TE birefringent modes are substantially aligned by said heating.

6. A method as claimed in any previous claim wherein said step (a) further comprises masking said top surface with a thermally conductive material having an aperture defined therein through which the emmission from said laser passes.

7. A method as claimed in any previous claim wherein said waveguide device structure includes a core structure and said localized heating occurs between said core structure and said top surface.

8. A method as claimed in any previous claim 1 to 6 wherein said waveguide device structure includes a core structure and said localized heating occurs along an elongated track parallel to and spaced apart from said core structure.

9. A method as claimed in any previous claim wherein said structure comprises a sensor and localized heating causes the ablation of said top surface adjacent said core.

10. A method as claimed in claim 3 further

comprising the step of:

(b) depositing further material layers on said top surface so as to form a semiconductor device.

11. A method as claimed in any previous claim wherein said step (a) is repeated along predetermined intervals of said waveguide device structure so as to form a grating structure.

12. A method as claimed in any previous claim wherein said method is utilized to provide for accelerated aging of a portion of said waveguide.

13. A method as claimed in any previous claim wherein said method is used to anneal UV sensitive portions of said waveguide.

14. A method as claimed in any previous claim wherein utilized to process an optical fibre device. 152.

An apparatus when constructed in accordance with the method as set out in any one of claim 1 to claim 14.

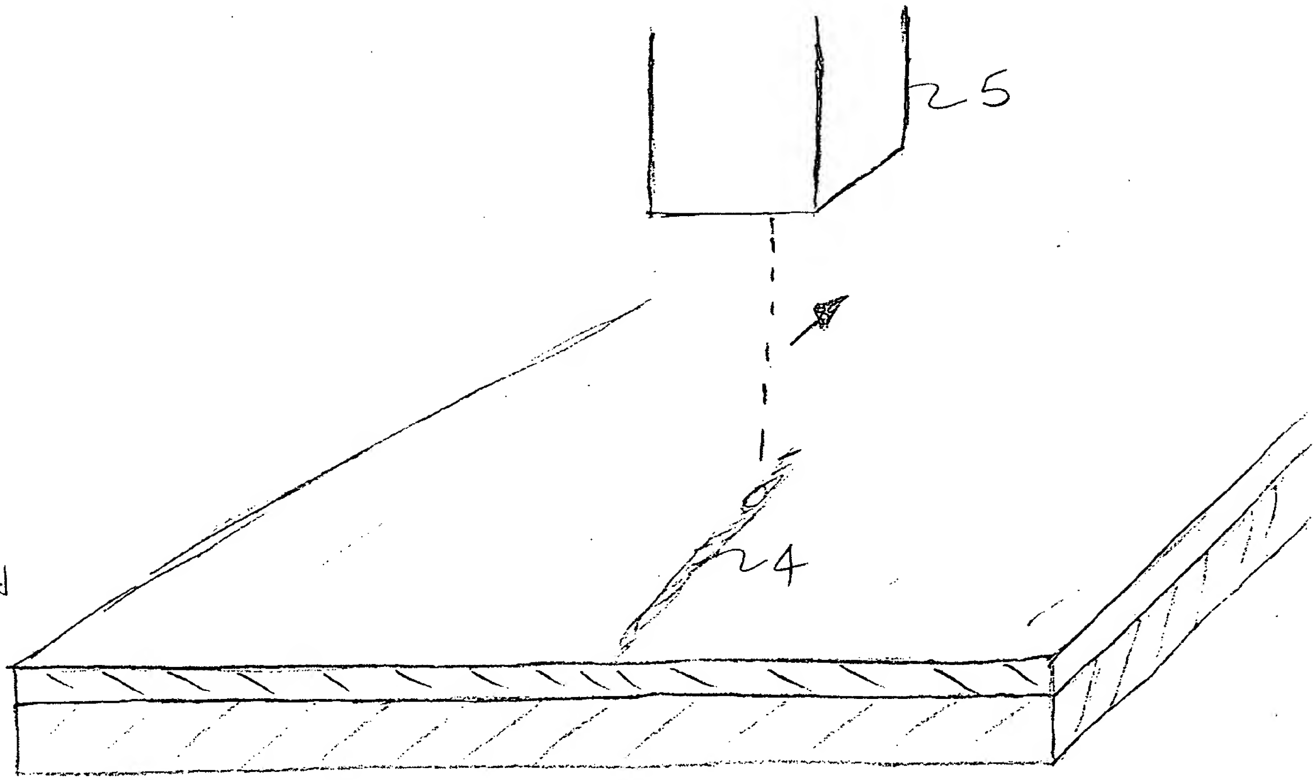


Fig. 2

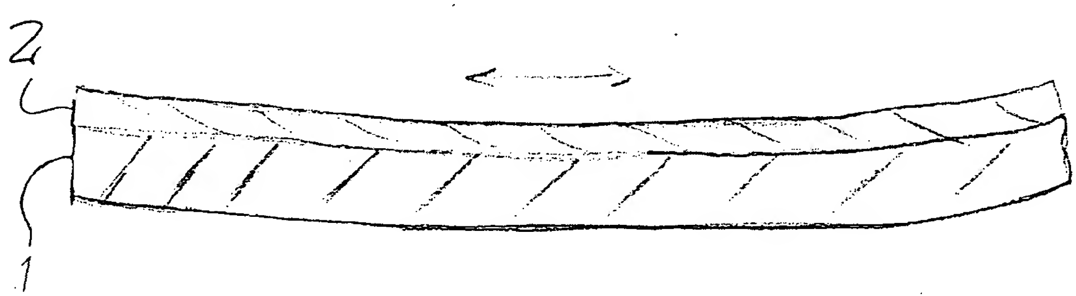


Fig. 1

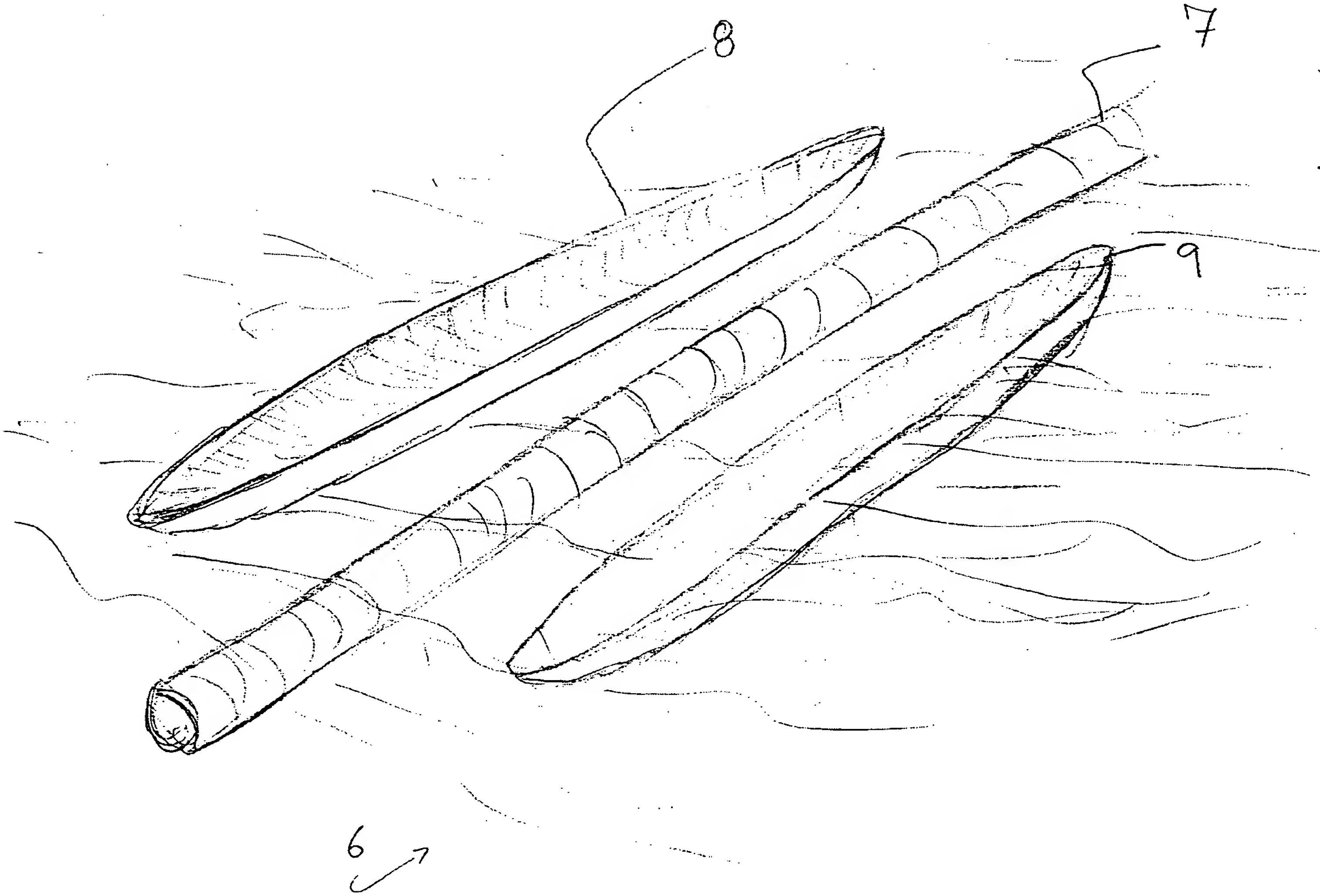
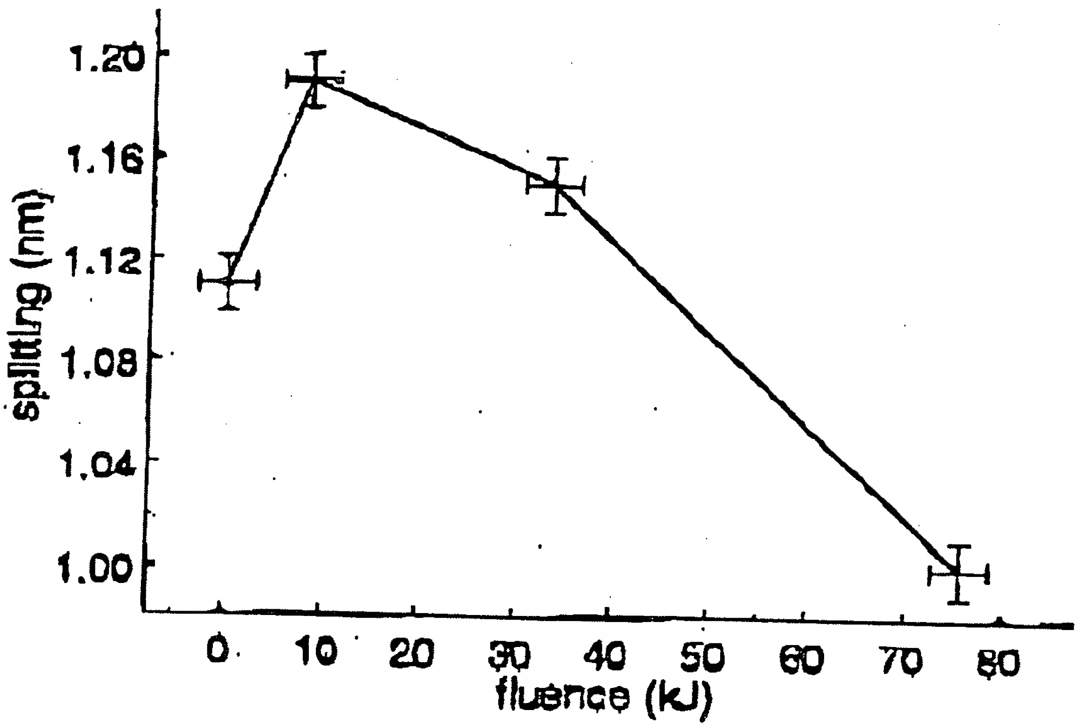
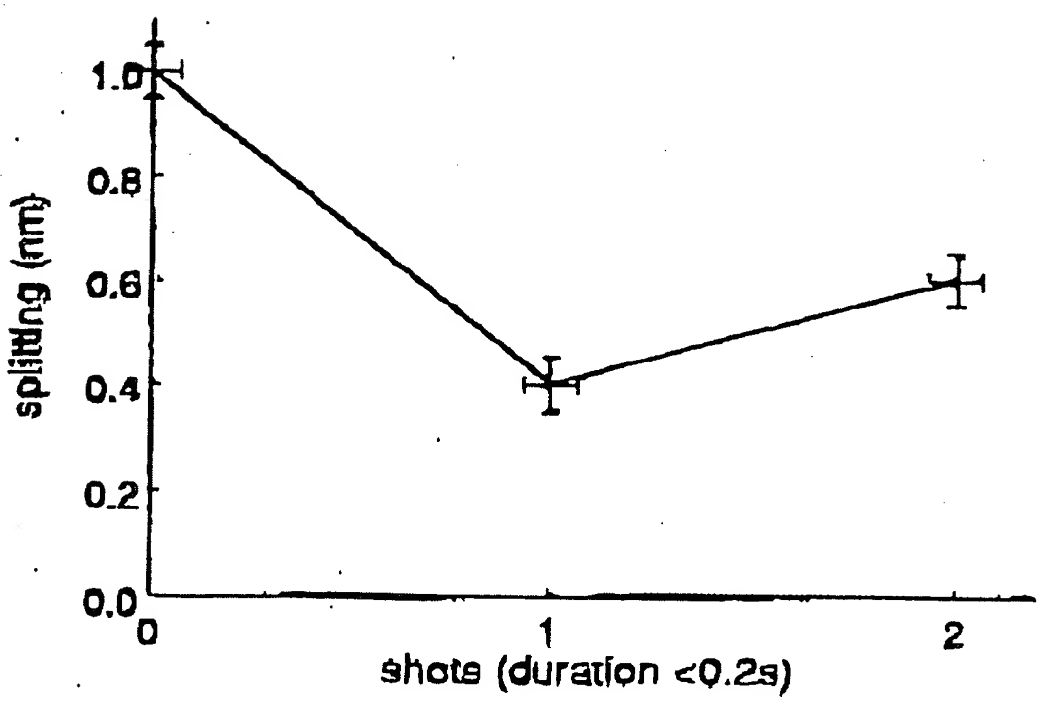


Fig. 3



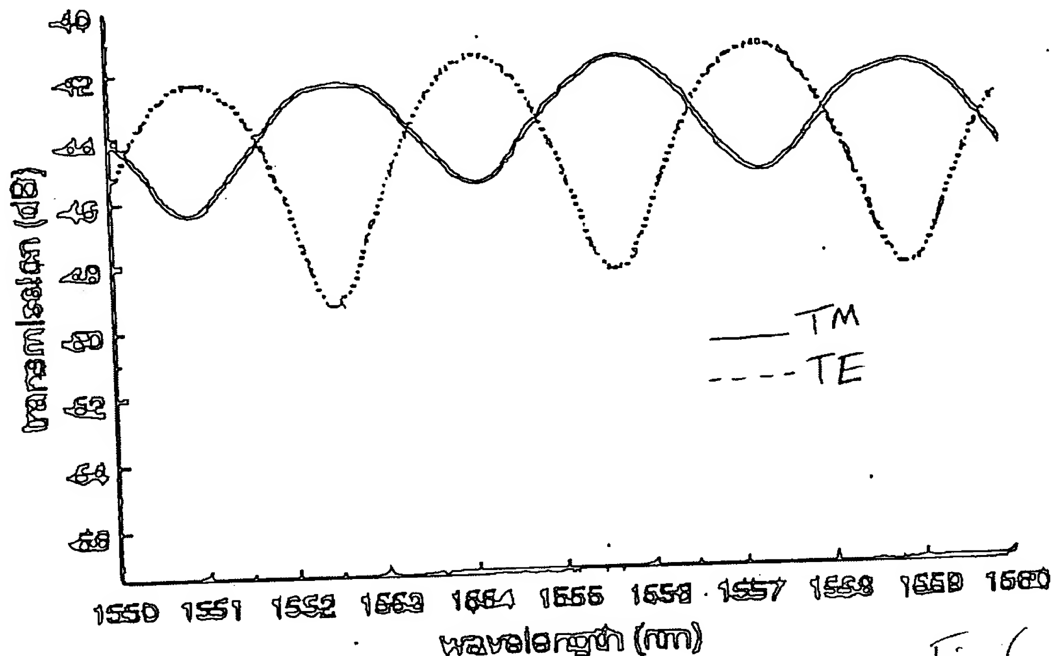
1.20
1.16
1.12
1.08
1.04
1.00
splitting (nm)
0
10
20
30
40
50
60
70
80
fluence (kJ)

Fig. 4



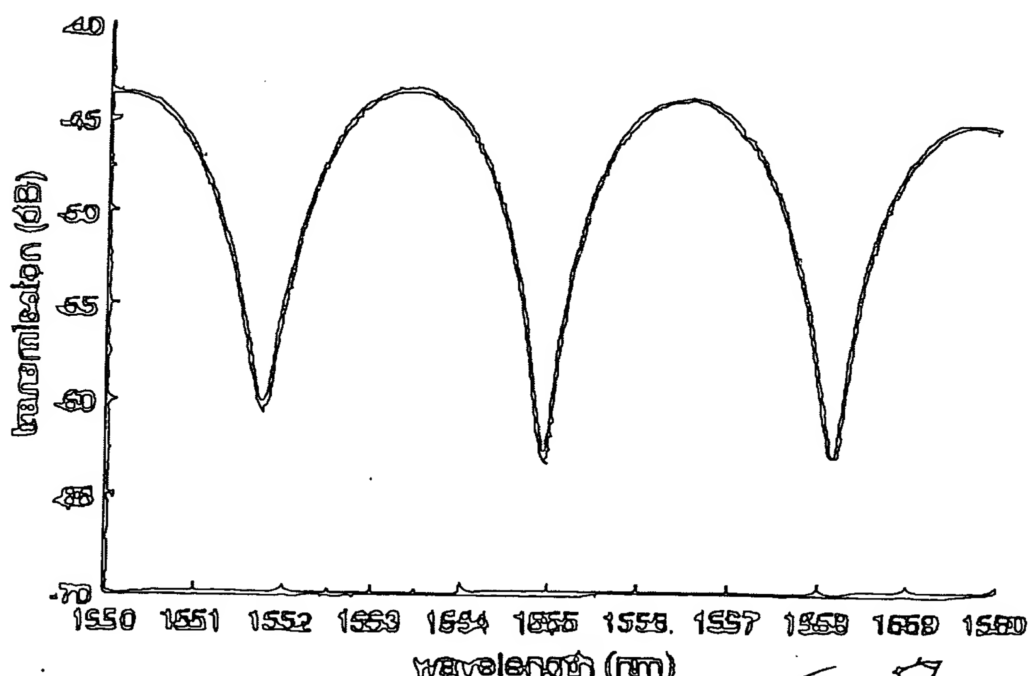
1.0
0.8
0.6
0.4
0.2
0.0
splitting (nm)
0
1
2
shots (duration <0.2s)

Fig. 5



transmission (dB)
wavelength (nm)
TM
TE

Fig. 6



transmission (dB)
wavelength (nm)

Fig. 7

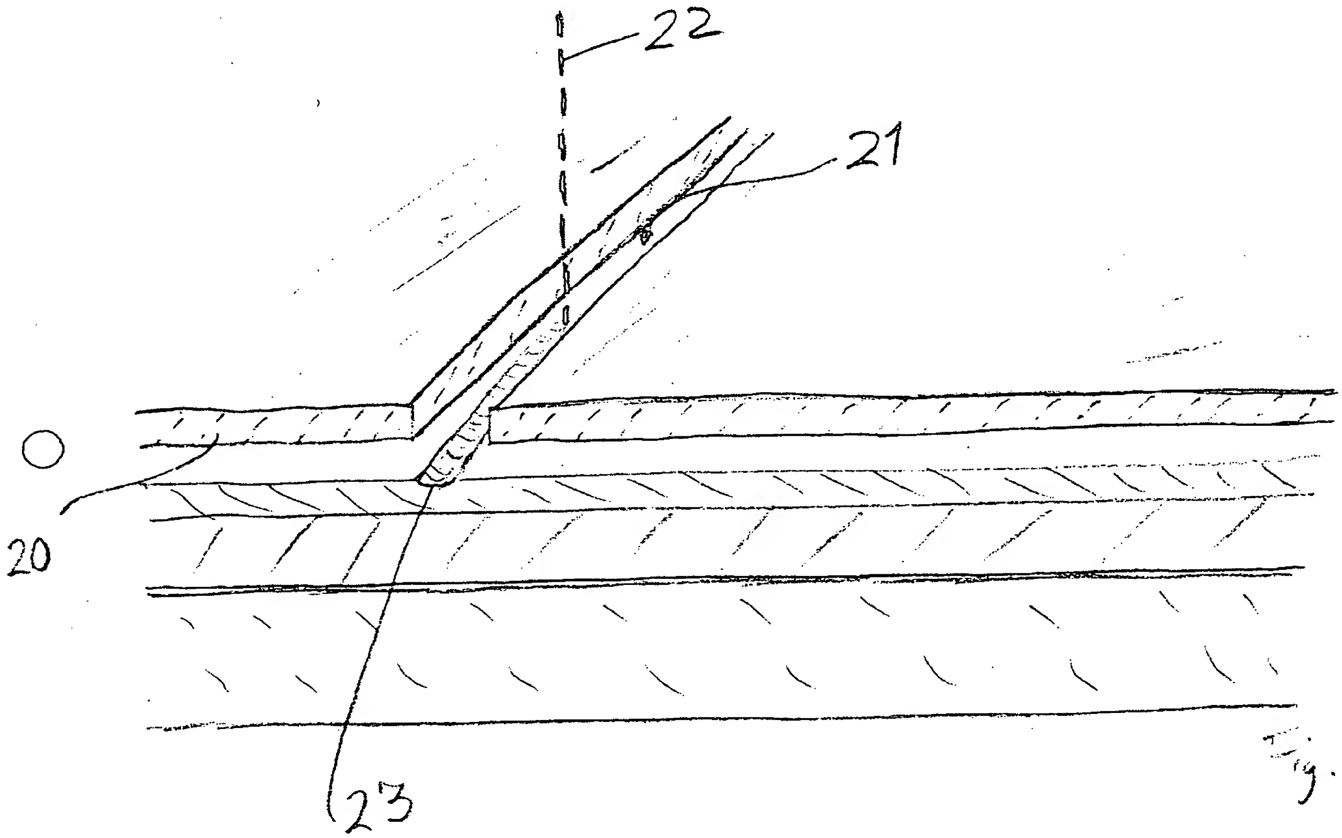


Fig. 8

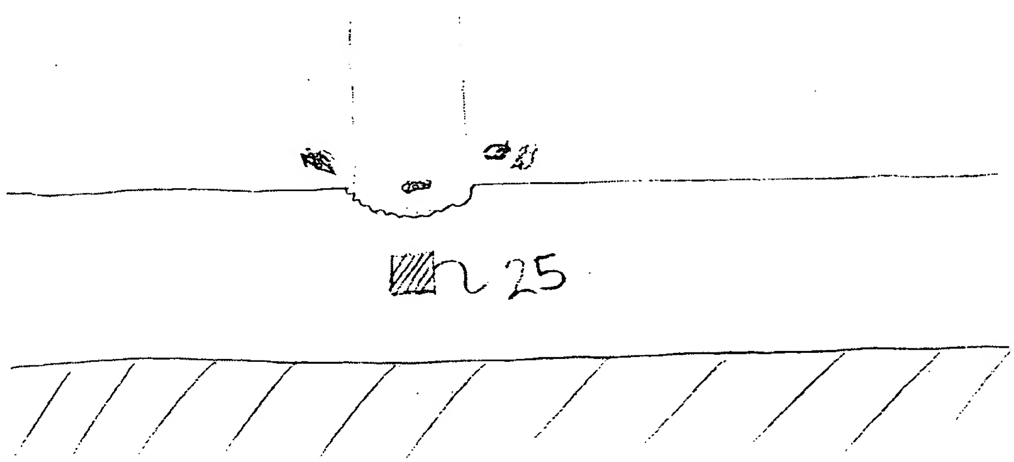


Fig. 9

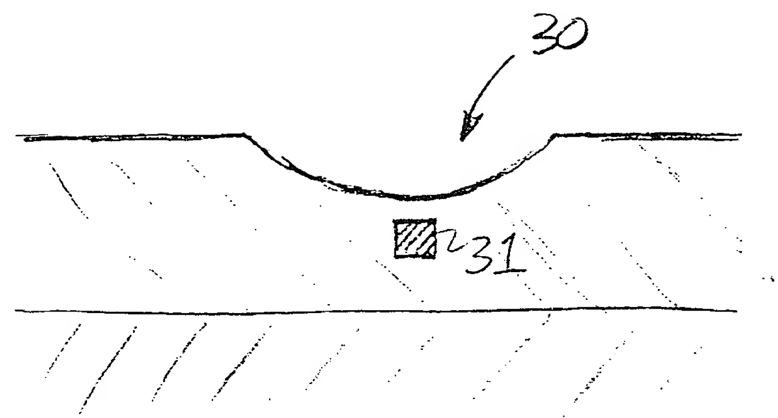


Fig 10

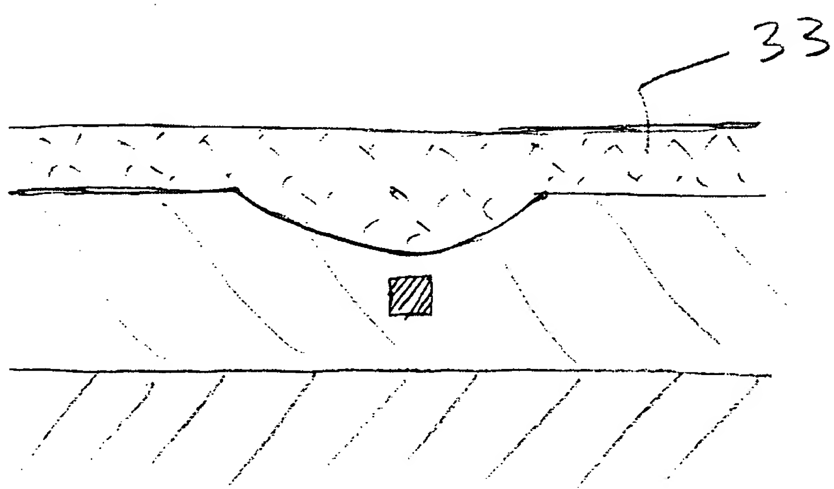


Fig. 11

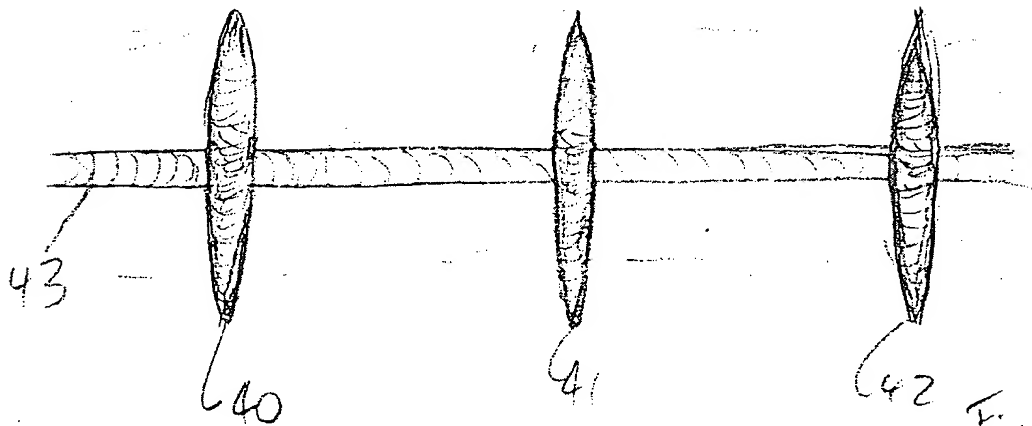


Fig 12

Abstract

A method of processing a waveguide device structure formed in a layer deposited on a substrate, the method comprising the step: (a) utilizing a laser device to provide predetermined localized heating of a top surface of the layer. The laser can comprise a carbon dioxide laser source. The heating preferably can include ablation of the top surface of the structure. The localized heating can be utilized to alter the birefringent properties of the structure.